



Division of Agricultural Sciences

UNIVERSITY OF CALIFORNIA

OLIVE HARVEST MECHANIZATION IN CALIFORNIA



R. B. FRIDLEY

H. T. HARTMANN

J. J. MEHLSCHAU

P. CHEN

J. WHISLER

CALIFORNIA AGRICULTURAL
EXPERIMENT STATION

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This bulletin summarizes more than 20 years of research on the mechanical harvesting of olives in California. Results demonstrated that mechanization can be aided by (1) use of a well designed machine; (2) harvesting healthy, properly pruned trees with limb structures strong enough to withstand the vigorous shaking required; (3) proper management; and (4) a satisfactory fruit abscission-inducing chemical, which has yet to be found. However, if only the first three conditions are satisfied, mechanical harvesting can be practical and economical even now. Under these conditions, some fruit will remain on the trees, but the savings in harvest cost compensates for this loss of fruit.

Included also are reports on basic studies of mechanical shaking, fruit damage, fruit collection, abscission-inducing chemicals, and pruning for mechanical harvest. The mechanical harvester, developed in line with the basic studies, is described herein, along with the field test results.

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The Authors:

R. B. Fridley is Professor of Agricultural Engineering and Agricultural Engineer in the Experiment Station, Davis.

H. T. Hartmann is Professor of Pomology and Pomologist in the Experiment Station, Davis.

J. J. Mehlschau is Assistant Development Engineer, Department of Agricultural Engineering, Davis.

P. Chen is Assistant Agricultural Engineer, Department of Agricultural Engineering, Davis.

J. Whisler is Staff Research Associate II, Department of Pomology, Davis.

OLIVE HARVEST MECHANIZATION IN CALIFORNIA¹

Olive production within the United States is concentrated in California, where about 50,000 tons are produced annually on 28,000 acres. The fruits are used primarily for canning as table olives. In most years, less than 10 per cent of the crop is crushed for oil—as a means to salvage substandard fruit. About 10 per cent of the table olive crop is canned as green-ripe or Spanish green olives, and 90 per cent is processed as black-ripe olives. Canning olives are picked in late September, October, and early November, when most of the fruits are pale-green or straw-colored. In contrast, most olives crushed for oil are fully mature, black, and sometimes are shriveled or frost-damaged. In California, oil olives are harvested in December or January (Hartmann and Opitz, 1966).

In the Mediterranean countries, such as Spain and Italy, mechanical harvesting would apply mostly to oil olives, which are picked in late fall or early winter. In California, on the other hand, table olives in the green-to-straw-color stage are the primary target for mechanical harvesting. Harvest conditions for table olives are different in some respects from those of oil olives. Therefore, the solutions to their mechanical harvesting problems are different as well.

Harvesting accounts for 50 to 70 per cent of the total cost of olive production and usually amounts to 35 to 45 per cent of grower's gross return. Cost of harvest is steadily increasing and is amplified by the difficulty in finding experienced pickers. Inexperienced pickers work at relatively slow rates, causing harvest costs to rise and creating a need for more workers at the peak of harvest in order to harvest fruit at optimum maturity.

Typical hand-harvest rates for good pickers may range from 400 to 800 pounds per day, and the cost of labor varies from about 70 dollars per ton to over 125 dol-

lars per ton, depending upon the growing area, tree size, fruit size, and crop on the tree. Hand-harvested fruits are usually picked from the tree by use of ladders. The fruits are placed into strap-on buckets, which are dumped when filled into 35- to 40-pound-capacity field boxes. Some growers use 1,200-pound-capacity bulk bins. Normally, within 14 hours or less after picking, the fruits are delivered to the processing plant.

In some countries, small rakes are used to remove olive fruits from the trees, but this is not done in California. Here, some oil olives are harvested by placing canvas on the ground, then knocking the fruits from the trees by beating the limbs with poles. However, this method sometimes injures fruiting branches and spreads the bacterial disease, olive knot (*Bacterium savastanoi*). Limited trials with pick-up machines for oil olives have shown some promise, but the method has not been generally adopted, because of the limited oil olive harvest and because of the difficulty of soil preparation. Tree shakers and catching frames designed for use with deciduous tree fruits have been used to a limited extent by a few California growers, mostly for harvesting oil olives. One grower reports a savings in labor costs of 60 dollars per ton with commercial equipment operated by four men with a harvest rate of 450 pounds per hour. Most oil olives are still hand picked.

Nearly thirty years of research

Extensive studies of mechanical harvesting have been carried on in California since the early 1940's (Fairbank, 1946; McKillop, Perry, and Shultis, 1955; Lamouria and Hartmann, 1955; Lamouria *et al.*, 1961). By 1952, sufficient progress had been made to stimulate a long-range project on olive harvest mechanization, which has been carried on by the University of California Agricultural Experiment Station,

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with the departments of Agricultural Engineering and Pomology cooperating. Some phases of the project were cooperative with the University of California Department of Food Science and Technology, with the Agricultural Engineering Research division of USDA, and with the University of California Agricultural Extension Service.

The University of California departments of Agricultural Engineering and Pomology surveyed various removal techniques, many of which were discussed by Lamouria and Hartmann (1959), by Bensoussan and Garbi (1958), and by Bensoussan and Landgarten (1959). By 1955, an experimental boom shaker was developed (Lamouria and Hartmann, 1955). At that time the processors became concerned about the marketability of mechanically harvested fruit; consequently, research from 1955 to 1960 emphasized fruit quality. This research demonstrated that the quality of machine-picked and hand-picked olives is virtually the same when processed by the black-ripe method (Lamouria and Hartmann, 1959).

In 1960 the University received its first grant of Olive Advisory Board funds for mechanical harvest research; this was followed later by several additional grants for continuation of the studies.

Before 1961, harvest techniques tried experimentally were: air blasts plus catcher, mechanical combing plus catcher, explo-

sives plus catcher, boom and cable shakers plus catcher, inertia shaker (both limb and trunk types) plus catcher, knockers plus catcher, water jet plus catcher, and picker-positioning aids. All of these techniques had one or more of the following shortcomings: low fruit-removal percentages, slow operation, excessive tree damage, and reduced fruit quality. The use of mechanical tree shakers showed the greatest promise.

Efforts to attain satisfactory results with conventional type tree-shakers, therefore, were focused on five areas of study. (1) fundamentals of tree shaking; (2) fruit injury; (3) use of chemicals to induce fruit abscission; (4) modifications of pruning techniques, and (5) development of shaking equipment specifically adapted to the characteristics of olive trees (Brewer, 1965). By 1966 substantial information was available on the design requirements for a shaker and was analyzed by R. B. Fridley and B. M. Shawver (unpublished report). Such a shaker was built and tested during the 1966 and 1967 harvest seasons. Encouraging results led to the construction in 1968 of a catching frame which could be used in conjunction with this shaker.

In addition to reporting on the published works resulting from the various phases of olive harvest studies, every effort is made here to identify and give credit to those whose unpublished works also have benefitted the research.

BASIC STUDIES OF TREE SHAKING

Difficulty in removing olives by tree shaking is caused by a tree structure which is not well adapted to transmission of vibration, by a strong attachment between fruit and tree, and by a small fruit mass. Olive trees characteristically have irregularly shaped and placed primary scaffolds, and, in California, have been pruned to bear fruits on a dense growth of willowy branches located at or near the periphery of the tree and close to the ground. This dense growth of limbs, branches, and leaves results in a high amount of damp-

ing and presents a substantial inertial resistance to vibration transmission.

Fruit detachment factors

Measurements of removal forces, fruit weight, and the time required for various forces to cause fruit removal were taken (Lamouria and Brewer, 1965; Lamouria, Brewer, and Hartmann, 1962). Ease of detachment depends on the method of removal: if removal is by hand or by use of a comb, then the force required to pull a fruit from its stem is the measure. When

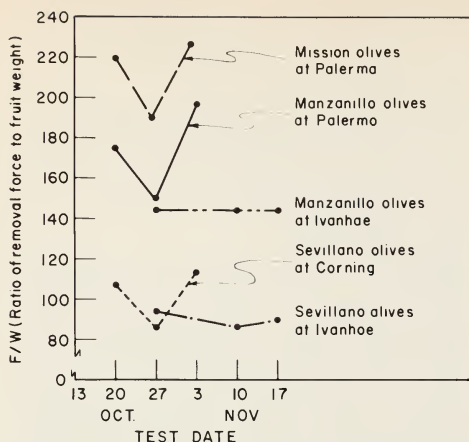
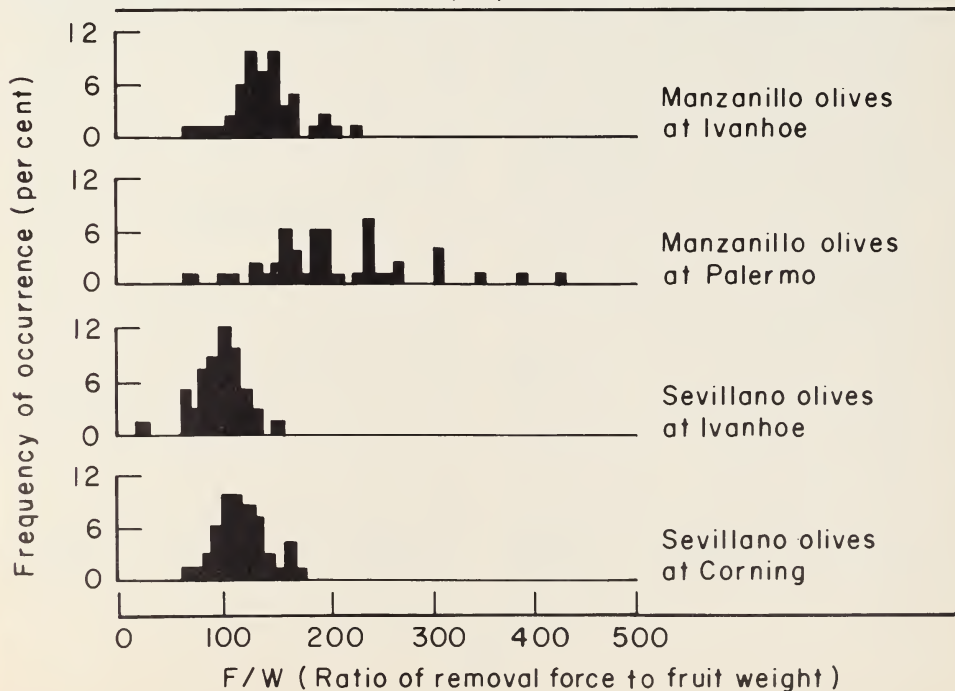


Fig. 1. F/W (the ratio of force required to detach fruit from tree to the fruit weight) for three varieties of olive fruits at three locations. Tree variety and location (or orchard conditions) substantially affect F/W, and F/W often tends to first decrease during the harvest season and then increase (Lamouria and Brewer, 1965).

the tree is vibrated sufficiently to detach fruit, then the weight of fruit and, to a lesser degree, the force-application rate are also determining factors.

The attachment of olive fruits to trees, as measured by the ratio of removal force to fruit weight (F/W), is very strong compared to that of most other fruit species. For instance, typical F/W values for olives are 100 to 200, depending on variety and orchard conditions, as compared to 30 to 70 for prunes. Tests indicate that as olives mature, the average F/W frequently decreases, reaches a minimum midway in the harvest season, and then increases (fig. 1), possibly due to fruit dehydration (and increased oil content in the fruit), with a resulting loss in weight. Late in the season, when the olives are used only for oil, the fruit attachment again decreases significantly. It has also been observed that the heaviest fruit are the easiest to remove, even though removal force increases with fruit weight. Sevillano fruits are large and have a low F/W, while Manzanillo fruits are smaller and have a high F/W. The variance of the F/W values is also important in results achieved with tree shakers. Figure 2 shows typical distribution of F/W values for individual olives and indicates that, in some in-

Fig. 2. F/W distribution of individual olives for two olive varieties at three locations (Lamouria and Brewer, 1965). The horizontal axis is an indicator of the intensity of shake required for removal of individual olives. Note the wide variability among conditions. (The height of each bar gives the per cent of olives within each F/W interval, that is, the frequency of occurrence at each F/W interval.)



stances, 5 per cent of the fruit has a F/W of at least twice the average F/W. Therefore, it is necessary to supply a vibration intensity at least double that indicated by the average F/W to achieve 95 per cent removal, since F/W is an indication of the amount of acceleration required for detachment.

Fruit-removal percentages

Early studies of fruit removal were made with a low-speed (400 to 600 cycles per minute), long-stroke (4.5 inches) boom-type shaker. This shaker provided good removal (83 to 93 per cent late in the season), but excessive limb breaking, throwing of fruit, poor maneuverability, and equipment breakdowns limited its acceptance (Lamouria and Hartmann, 1955). Subsequent studies included trials with many other combinations of frequency and stroke, ranging from 500 to 3,000 cycles per minute and 3 to 1 inches, respectively. The resulting data were analyzed in terms of the following empirical relationship developed for analysis of shaking prunes (Fridley and Adrian, 1966):

Where: per cent fruit removed =

$$100 - 100e^{-Ks^pn^u}$$

s = stroke (inches)

n = frequency (cycles per minute)

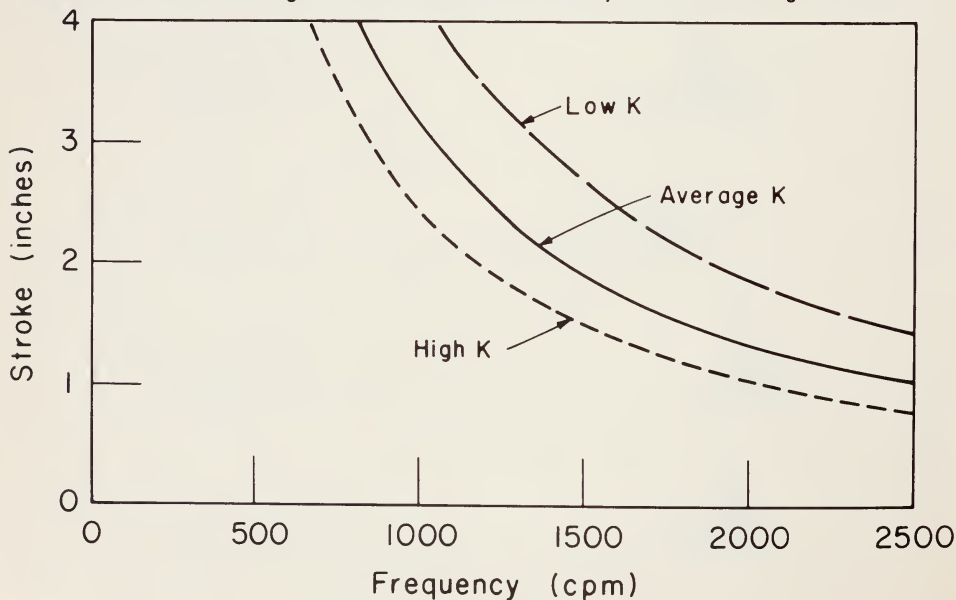
K, p, u = empirical factors determined experimentally

e = 2.718 (the base of natural logarithm)

Data for shaking olives were analyzed, and the factors p and u each were determined to be equal to 2. The average value of K was found to be 2.25×10^{-7} , but it varies greatly due to variability of conditions among trees, orchards, varieties, and climatic changes. A high value of K is associated with conditions which are conducive to good fruit removal.

The results plotted in figures 3 and 4 show the effect of frequency and stroke delivered to the tree limb on fruit removal. Figure 3 shows the substantial variation of frequency and stroke required to achieve specific fruit-removal percentage. This variation results from the variation in K ; the limits of each range represent ± 50 per cent variation from the average

Fig. 3. Range of frequency and stroke required by limb-type shaker to remove 80 per cent of olives. The range from high K to low K represents the variation resulting from different conditions, e.g., tree shape, F/W, and the like. A high K indicates the best conditions for removal; low K represents a poor fruit-removal condition. Average K is the condition most commonly encountered during the field tests.



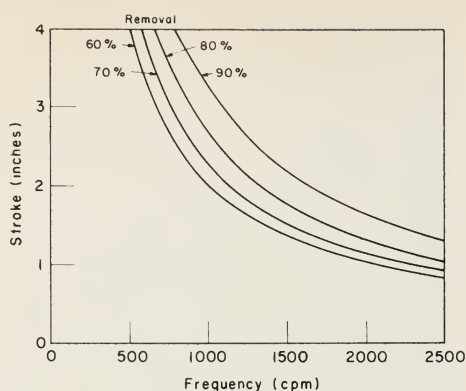


Fig. 4. Comparison of the frequencies and strokes required by limb-type shaker to remove 60, 70, 80, and 90 per cent of olives under average orchard conditions.

value of K , which covers most conditions. It should be pointed out that due to the variations encountered, substantially greater frequency and stroke are required under poor orchard conditions (low K) than those required under good orchard conditions (high K) for the same removal.

Results shown in figure 4 provide a comparison of the average fruit removal obtained resulting from different frequencies and strokes on all varieties. Varietal differences are reflected in the range shown in figure 3. Although the effect of variety upon removal is not entirely clear, it appears that Sevillano fruits are somewhat easier to remove with shorter than average strokes; with longer strokes, they tend to be difficult to remove. Because of the willowy growth habit of the trees, Manzanillo fruits seem to be slightly more difficult to remove by shaking than either Mission or Sevillano.

Tree damage

Damage to bark that is caused by the shaker clamp must be avoided. The bark is easily injured, and while some healing will take place naturally, repeated attachments of the clamp each year can prevent permanent healing and provide opportunity for attack by bacterial or fungus organisms. In California olive groves, the bacterial disease, *Bacterium savastanoi* (olive knot) is serious and very widespread. It occurs on the surfaces of the

tree, and any breaks or cuts in the bark will allow bacteria to enter the inner tissues to cause galls and, finally, in some cases, limb girdling.

Research on the subject of bark strength (Fridley and Adrian, 1966) provided criteria for design of a clamp, which, properly used and maintained, virtually eliminates bark damage. The clamp design is discussed on page 16. Bark damage can be avoided on almost all limbs when the clamp is properly adjusted and when reasonable care is used in the operation of the shaker, particularly in positioning the shaker perpendicular to the limbs.

Limb breakage resulting in extensive tree damage occurs with long strokes and low frequencies (near the natural frequency of the limb where resonance can produce large deflections). In fact, limb breakage is aggravated by long strokes at any frequency and by shaking for an extended time. The susceptibility of orchards to limb breakage is not easily predictable, but obviously weak limbs are particularly vulnerable (fig. 5). Many olive orchards in California have been top-grafted to different varieties once or, sometimes, twice. Graft unions, especially during the first several years after grafting, are not strong. The severe shaking action necessary to remove olives may break the limbs off at the graft union. However, trees that have not been top-grafted, or older, grafted trees with well-healed, strong graft unions are not likely to suffer such breakage. With experience, operators quickly learn to recognize limb structures and clamping positions which are particularly conducive to limb breakage.

Leaf drop (which can result from high shaking frequencies) during the fall and winter will result in subsequent flower and crop reduction. During the wet periods, leaf fall also predisposes the trees, particularly the Manzanillo variety, to olive knot infection. P. A. Adrian, R. B. Fridley, and C. R. Kaupke (unpublished report, 1959) observed that excessively high frequencies snap off olive leaves at the base of the leaf blade (fig. 6). The frequency at which leaf removal occurs is not a fixed value for all conditions, but above about 2,500 cycles per minute, in-



Fig. 5. Limb broken by mechanical shaking. Note the decay in the limb in break area.



Fig. 6. Limb with leaves removed by mechanical shaking at too high a frequency.

creasingly severe leaf removal has been noted. Leaf drop also increases with increased duration of shake.

Root injury does not appear to result from shaking. A more likely cause of damage to the roots (usually in the upper 2 feet of soil), as well as to the soil structure around the trees, is the use of heavy equip-

ment on soil that is wet, either from irrigation or following winter rains. In addition, compaction of the wet soil by heavy equipment can impede water penetration during subsequent irrigations. This would be likely if soil compaction occurred each year during the harvest season.

FRUIT-COLLECTING DEVICES

Two types of catching frames were tested by Lamouria, *et al.* (1961) for the collection of machine-shaken olives. One was a wrap-around "inverted umbrella" catching frame mounted on a tractor, and the other was a light-weight, hand-carried frame with sloping surfaces. The tractor-mounted unit was somewhat difficult to maneuver, but its greater disadvantage was interference with shaker operation. The hand-carried unit did not drain well; fruit tended to lie in pockets and required excessive labor.

Adrian, Fridley, and Kaupke (unpublished report, 1959) tested a self-propelled catching frame which consisted of two halves, one on each side of the tree, with sloping surfaces and powered conveyors to

collect fruit. They observed that the frame interfered with maneuvering and attaching the shaker, which was on a separate vehicle; the frame was also too small for large trees. Observations indicate the need for a catching area approximately square and extending a minimum of 5 feet beyond the tree on all sides. The canvas roll-out frames tested have generally been somewhat small, but they can easily be made larger. The primary problem is again maneuvering a second machine around the canvas and tree to shake all limbs. Also, when machines are driven over parts of the canvas, the canvas becomes dirty and a certain number of olives are crushed.

FRUIT INJURY DURING MECHANICAL HARVESTING

Quality index

To evaluate fruit injury, a rating system was devised by P. A. Adrian, R. B. Fridley, and C. R. Kaupke in 1959 (unpublished report): 4 = no damage; 3 = light visible scars, no skin breaks; 2 = heavily scarred and bruised, no skin breaks; and 1 = unacceptable with skin breaks, cuts, and indentations. Using these score numbers, an average quality index for a total sample (20 to 300 fruits) could be calculated as follows:

(Sample)

$$20 \times 4 = 80 \quad (20 \text{ fruits rated } 4)$$

$$50 \times 3 = 150 \quad (50 \text{ fruits rated } 3)$$

$$20 \times 2 = 40 \quad (20 \text{ fruits rated } 2)$$

$$10 \times 1 = 10 \quad (10 \text{ fruits rated } 1)$$

score 280

$$\text{quality index} = \frac{\text{score}}{\text{number of fruits}} = \frac{280}{100} = 2.80$$

Injury to olive fruits from mechanical shaking is caused by their hitting foliage or shoots before detachment, impacting branches during the fall through the tree, and impacting the catching surface. Some fruits have sustained skin breaks and severe bruises caused by high-velocity impact on limbs and other hard surfaces. Most fruit injury, however, consists of superficial scars, which do not break the skin or harm the fruits but give them an unsightly appearance. This is true when processing is done by the Spanish-green-fermented or the California green-ripe methods, where the final products remain green. When processed by the California black-ripe method—and presumably by the black fermented method—such scars are completely obliterated. In fact, during repeated tests using fruits processed by the black-ripe method, it has been difficult to distinguish between hand-picked and machine-harvested fruits.

The effect of fruit variety and maturity upon fruit quality after mechanical harvesting has not been well established; however, Manzanillo, Mission, and Sevillano fruits do not appear greatly different in

their ability to resist injury. There appears to be less injury as the fruits mature.

Vibration effects

Fruit vibration during detachment can affect fruit quality. Excessive motion injures the fruit by whipping them against branches, foliage, or other fruits. Also the fruit can be excessively scattered, making collection difficult. The excessive motion can be caused by unstable vibration of the fruit-stem system observable as very erratic motion and violent whipping of the fruit.

A mathematical model developed by Studer (1966) established the zone of stable motion for pendulous fruit systems. In this model, the fruit-stem was represented by a pendulum with l being the distance from the pivot point to the center of percussion, r representing the amplitude by which the pivot point was displaced, and ω representing the frequency of oscillation. Depending upon the relative magnitudes of r , l , and ω , two distinctly different types of pendulum motion are possible, namely stable and unstable. In terms of shaker design, the stability diagram (fig. 7) shows that as frequency is increased (moving from right to left on the graph), larger shaker strokes (amplitude parameter) can be used with stability (shaded area) still maintained. Note that shaker stroke refers to the amplitude of vibration where the fruit-stem system is attached to the branch.

Field results observed throughout the olive harvest research seem to bear out this prediction. Table I compares the predictions from theory with experimental measurements of fruit motion as affected by vertical vibration of Manzanillo and Barouni olives. About 96 per cent of the Barouni olives exhibited the predicted motion, probably because the short stem and long fruit was most similar to the ideal pendulum used for theoretical consideration in the model.

Duration of shake

Studies have shown that the fruit damage which occurs when the fruits are whipped

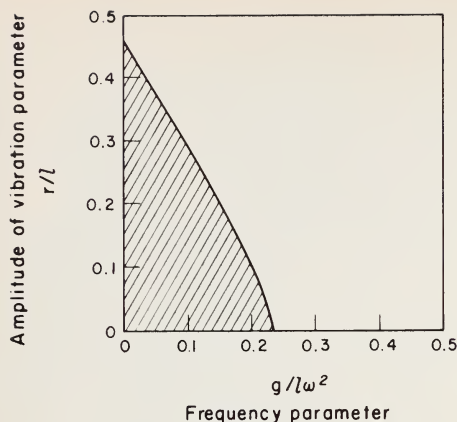


Fig. 7. Stability diagram for vertical vibration of a fruit-stem system. Shaded area represents the zone of stable vertical vibrations on a fruit-stem system. On the vertical axis the symbol r is the amplitude of vibration (inches) and l is the effective length (inches) of the pendulum. On the horizontal axis ω is the frequency (radians per sec), l is the effective length (inches) of the pendulum (inches), and g is the acceleration of gravity (386 inches per second²). For olives, l was taken equal to the stem length plus one-half the fruit length (Studer, 1966). Note that the frequency term, ω , is in the denominator of the frequency parameter; therefore, high frequencies are toward the left and low frequencies toward the right on the horizontal axis.

about in the tree before they drop can be reduced somewhat by shaking for very short periods. Fruits which drop immediately after the first one or two cycles are practically undamaged, whereas those dropping after shaking has continued for a prolonged period are more heavily damaged. In one field trial, dead twigs and excess shoots in the tree were pruned out before shaking to lessen twig contact as the fruits dropped; this did not reduce the amount of damage.

In a series of tests conducted on Sevillano olives by P. A. Adrian, R. B. Fridley, and C. R. Kaupke (unpublished report, 1959), the shake was varied from 2 to 32 seconds. Although fruit removal percentages increased with duration of shake from 17 to 86 per cent, the fruit quality index showed a decrease of about 5 per cent. Shaking for less than two seconds was less damaging. However, high intensity of shake during the short period was necessary for economic removal.

TABLE I
COMPARISONS IN LABORATORY TESTS BETWEEN THEORETICAL PREDICTION AND MOTION OF MANZANILLO AND BAROUNI OLIVE FRUITS ACTUALLY EXHIBITED WHEN FRUIT-STEM SYSTEMS WERE SUBJECTED TO VERTICAL VIBRATION

Parameters of applied vibration		Fruit motion	
Amplitude*	Frequency	Prediction†	Fruits exhibiting predicted motion
<i>inches</i>	<i>cpm</i>		<i>per cent</i>
Manzanillo			
0.25	450	stable	100
1.0	450	unstable	100
0.25	650	stable	100
1.0	650	unstable	100
Barouni			
0.125	450	stable	88
0.25	450	unstable	86
0.50	450	unstable	100
0.125	550	stable	90
0.25	550	stable	89
0.125	650	stable	100
0.25	650	stable	96
0.125	750	stable	100

* Amplitude is equal to one-half of stroke.

† Unstable = vibration observable as very erratic motion and violent whipping of the fruit; stable = motion sufficient to vibrate fruit without erratic motion or violent whipping.

Collection injury

Tests were made to determine the best possible material for padding the catching surfaces of a mechanical olive harvester by H. L. Brewer (unpublished report, 1965). Olives were selected at random and dropped from various heights, either singly or in combination, onto surfaces padded with several different materials. Quality indexes were calculated based on evaluation of the fruit three days after dropping. Results showed that fruits dropped from 5 feet or more onto a 1/4-inch plywood surface would produce a quality index of less than 2. Data indicated the need for good padding over hard surfaces. Among the best materials were ethafoam covered with a 6-mil film

TABLE 2

FRUIT CONDITION AND QUALITY RATING OF HAND PICKED MANZANILLO
OLIVES COMPARED TO THOSE COLLECTED BY VARIOUS OTHER
MEANS FOLLOWING MECHANICAL SHAKING

Collection method	Fruit when graded*	Per cent of olives with:				Quality index†
		No damage	No skin breaks, light scars	No skin breaks, heavily scarred and bruised	Skin breaks, cuts and indentations	
Hand-picked (control)....	Fresh	52	33	15	0	3.37
	black-ripe	90	8	0	1	3.90
	green-ripe	60	39	1	1	3.56
Canvas on ground.....	fresh	14	34	52	0	2.59
	black-ripe	83	14	2	1	3.79
	green-ripe	7	81	10	2	2.93
Canvas on pad.....	fresh	25	51	24	0	3.01
	black-ripe	74	23	1	1	3.72
	green-ripe	22	67	10	1	3.10
Catching frame.....	fresh	24	48	28	0	2.96
	black-ripe	64	30	5	1	3.57
	green-ripe	31	50	17	1	3.16
Hand-held net.....	fresh	41	44	15	0	3.25
	black-ripe	72	24	3	1	3.67
	green-ripe	47	37	14	1	3.32

* Fresh fruits were graded for visual observation 2 to 3 days after harvest. Black-ripe and green-ripe fruits were graded by visual observation after processing and canning.

† See page 9 for method of calculation.

of plastic (yielding a quality index of 3.96 to 4.00) and ¼-inch polyurethane covered with a 6-mil plastic film (yielding a quality index of 3.90 to 3.98).

Fruit can more easily withstand being dropped on other fruit than on a hard surface. The filling of orchard field boxes, which are generally fairly shallow, exposes much of the fruit to bruising as a consequence of hitting the bottom of the box during filling. Because all of the first layer of fruit can be assumed to hit the bottom, a greater percentage of fruit is damaged in shallow boxes than in deep ones. Also, experience indicates that the harder the raw fruit texture the greater the bruising upon impact; it is likely that more of the kinetic energy of falling is absorbed by rupturing the cells rather than causing elastic deformation. Thus, a means of filling boxes which will further decrease fruit damage is desirable.

Determinations of fruit injury resulting

from fruit falling onto different types of catching surfaces were made during the 1967 season by the authors. Hand-picked fruit was used as a control, and samples either were put in field boxes for conventional handling or were placed immediately into a 7 per cent brine solution.

Catching surfaces used following mechanical shaking were: (1) a hand-held butterfly net—expected to produce no more damage than that incurred in the tree; (2) a catching frame specifically designed with padded surfaces and decelerator strips to provide fruit protection; (3) a canvas laid on the ground (the least expensive method); (4) a ¾-inch thick polyurethane pad placed on canvas laid on the ground.

Three 100-fruit samples of each treatment were graded two to three days after harvest and classified by the quality index described on page 9. Results are given in table 2.

Some fruit injury occurred in the tree, but it was less than expected and no more important a factor than injury from fruit falling onto catching surfaces. About one-half of the injury observed with the polyurethane pad on canvas, or the catching frame was due to shaking or due to fruit falling through the tree; fruits caught on these surfaces showed about equal amounts of damage, about half that for fruits caught on plain canvas laid on the ground. Although the pad-on-canvas gave results comparable to that of the catching frame, samples from the frame were collected at the end of the conveyor and those from the pad-on-canvas were taken directly from the catching surface. Thus, any injury resulting from the contact of olives and debris during transfer of fruit

from the catching surface to the conveyor is not included in the data obtained with the padded canvas.

These results indicate that bruising of fruit caught on unprotected canvas is largely due to clods, rocks, or firm soil under the canvas, and that an elaborate catching frame with decelerator strips is not necessary if the canvas can be padded, held off the ground, or used on a smooth, possibly grass-covered surface. From this, it was decided that a suspended canvas, roll-out type, catching frame would give results similar to those obtained with padded canvas and would be capable of delivering fruit to a handling system where the debris and the fruit could be separated with minimum agitation.

PRUNING FOR MECHANICAL HARVESTING

Proper pruning is important for good fruit removal with mechanical harvesting. Studies have shown that shaker vibration transmission is a function of limb configuration, damping (primarily caused by viscous drag), and mass distribution (Hoag, 1968), all of which can be modified by pruning. Poor vibration transmission results in poor removal even if fruit attach-

ment forces are weak. The evidence for this is that most fruits which are not removed are concentrated on relatively few limbs rather than uniformly distributed throughout the tree. Limbs from which fruits are not removed are those that move very little during the shaking operation.

During the first several years of tree growth, therefore, some light pruning dur-

Fig. 8. Mature Manzanillo olive tree before (left) and after reshaping (right) by pruning for better adaptability for mechanical harvest.



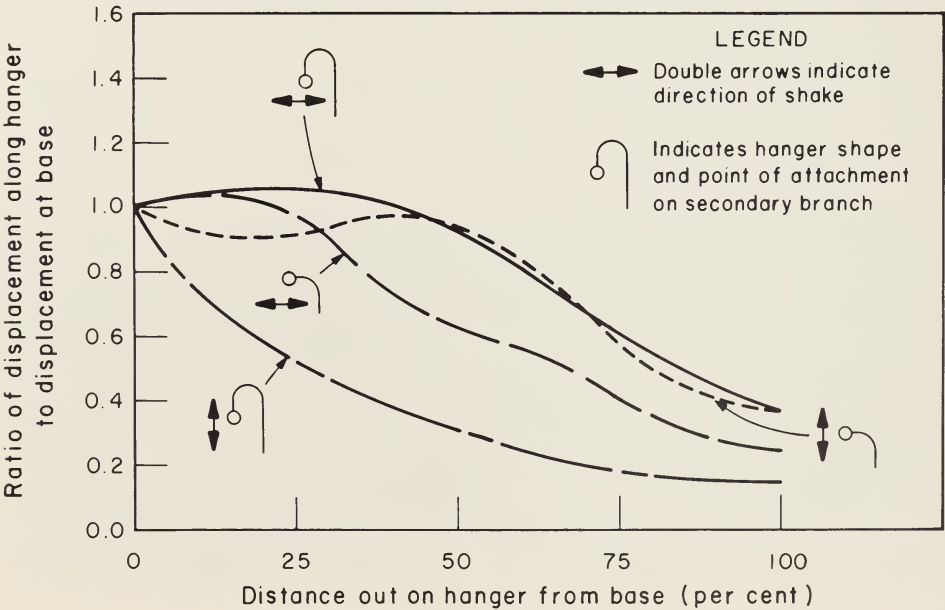
ing the growing season can develop a trunk and primary scaffold limbs satisfactory for subsequent mechanical harvesting. During the first productive years, yield of trees properly pruned for mechanical harvesting are reduced somewhat by this procedure in comparison with that of unpruned trees, but when mature, these trees will show a greater yield than the unpruned. (Hartmann, Opitz, and Hoffman, 1960).

Most suitable tree shape

The tree configuration best suited for mechanical harvesting is open and vase-shaped with four to six scaffold branches and no low, hanging branches below a height of 6 feet (see figs. 8 and 9). Some secondary scaffold branches readily give up their fruit to shaking; others, especially those that are sharply curved, do not (Lenker, 1963). Vibration transmission of hanging branches is illustrated in figure 10.



Fig. 9. Above. Young olive trees modified for future mechanical harvesting. Left. Three-year-old tree. Right. Six-year-old tree. Fig. 10. Below. Vibration transmission from base of branch out to end of branch for different types of hanger branches (Lenker, 1963).



ABSCISSION-INDUCING CHEMICAL AGENTS

The olive does not have a definite or predictable period of natural fruit abscission as do many other fruit species. If not harvested, olives often hang on the tree until the following spring, dropping throughout the winter. Since the fruits for California table olives are harvested when horticulturally immature, a spray material that would function to initiate the development of an abscission layer at any point in the fruit peduncle obviously would facilitate fruit removal at the time intended for harvest. An abscission-inducing agent should:

1. Be inexpensive.
2. Leave no toxic residues on the fruit. USDA registration is required for commercial use of such materials.
3. Not cause excessive leaf removal.
4. Not interfere with flower formation the following year.
5. Not reduce the quality of the processed product or impart undesirable off-flavors.
6. Be active under a range of weather conditions and be effective with the commercial olive varieties.

Many chemicals, including some organic acids and some coded compounds, have been tested as abscission-inducing agents (Hartmann, 1955; Hartmann, Fadl, and Whisler, 1967; Hartmann, Heslop, and Whisler, 1968; Hartmann, Tombesi, and Whisler, 1970; and Gellini, Falusi, and Sabato, 1966). In some tests, chemicals have reduced the attachment force to one-tenth that for untreated fruits. However, three general problems have been encountered: First, the agents used cause leaves to abscise along with fruits. Second, absorption of chemicals that induce abscission is often affected by humidity and, to a lesser extent, by temperature during and after application. High humidity and cool weather increase effectiveness of some materials; low humidity and warm temperatures are more effective with others. Third, some chemicals cause leaf burning or fruit pitting. Thus, the determination of required concentrations, and the adjustments which may be neces-

sary to meet various weather conditions is not simple, even after an effective chemical has been selected. The margin between no results and excessive fruit damage or loss of leaves seems small.

Of the materials tried in the early phases of these studies (Hartmann, 1955), only maleic hydrazide, believed to have anti-auxin activity, showed any indication of inducing fruit abscission. To be effective, the 1.0 per cent concentration required had to be applied under high humidity conditions, such as in winter during foggy weather. At low humidity levels, it did not seem to be absorbed by the plant. Although maleic hydrazide did not cause any adverse effects to the trees, the cost of the material at this concentration makes it uneconomical.

Gellini (1964) in Italy found ascorbic acid to be effective in inducing olive fruit abscission; sprays of glycerine were also effective. In California, Hartmann, Fadl, and Whisler (1967) induced olive fruit abscission at concentrations of ascorbic acid ranging from 0.125 to 2.0 per cent, but only under almost saturated air-moisture levels. Defoliation was unacceptably high, however, under these conditions. With low humidity, abscission effects were absent, due, apparently, to lack of absorption by the leaves.

In Florida, iodoacetic acid was used by Hendershott (1965) in causing abscission of citrus fruits. Hartmann, Fadl, and Whisler (1967) also found that this chemical caused abscission of olive fruits in California but only if applied under high humidity conditions and when used with a wetting agent.

Ethephon (chloroethylphosphonic acid), caused abscission of olive fruits under low humidity conditions (Hartmann, Heslop, and Whisler, 1968; Hartmann, Tombesi, and Whisler, 1970). This material, which releases ethylene under alkaline conditions, also caused excessive leaf abscission, which was reduced to some extent by sprays with an auxin, naphthaleneacetic acid, applied two to three days following the ethephon sprays. Leaf drop, however, still tended to be excessive, interfering

with flower formation for the subsequent crop. Urea, added to ethephon at 1.35 per cent, presumably increased absorption and effectively induced abscission. Rains falling within a day after ethephon application tended to nullify its effects. Both fruit and leaf abscission from ethephon sprays are greater under warm rather than cold conditions. The Mission variety was the most responsive to ethephon, followed by Manzanillo, Barouni, Sevillano, and Ascolano, respectively (Hartmann, Tombesi, and Whisler, 1970).

No completely satisfactory fruit abscission-inducing chemical has, at this time, been found for the table olive harvest in California. Materials, such as ascorbic acid,

maleic hydrazide, and iodoacetic acid, which are effective only under high humidity conditions, are of little value during the table olive harvest season—mid-September to mid-November—when humidity levels are generally quite low. Attempts to artificially increase air moisture levels, following application of these chemicals, by applying a mist with overhead sprinklers or spraying the trees with water, have been unsuccessful in enhancing the abscission effects.

Even though its defoliation effects were reduced by subsequent applications of naphthaleneacetic acid, ethephon, with urea, interfered with flower formation for the following crop.

HARVESTER DESIGN

Tree shaker design

Upon completion of the basic tree-shaking studies, an inertia shaker was designed, built, and tested specifically for olive trees (fig. 11). Information gained prior to 1966 was used in selecting ranges of stroke and frequency which were expected to give approximately 90 per cent fruit removal without excessive tree damage. To obtain a wider diversity of data and thus determine optimum frequencies and strokes more precisely, as much versatility as practicable was built into the machine.

A slider-crank mechanism provided the oscillatory force for the shaker (Fridley and Adrian, 1966). Power was delivered to the crankshaft from a hydraulic motor

capable of delivering up to 75 horsepower to achieve the vigorous shake required to remove olive fruits. A four-strand roller chain drive (No. 35) provided speed reduction from the motor to the crankshaft. Design speed was approximately 1,200 cycles per minute. The hydraulic circuit included a quick opening solenoid valve and an accumulator to provide a high initial acceleration for quick removal with minimum damage to fruit and tree.

Three discrete strokes of 6 inches, 5¼ inches, and 4½ inches were designed into the crank mechanism. The stroke delivered to the tree varied with limb size and point of attachment, as well as with crank throw in the machine, and was meas-

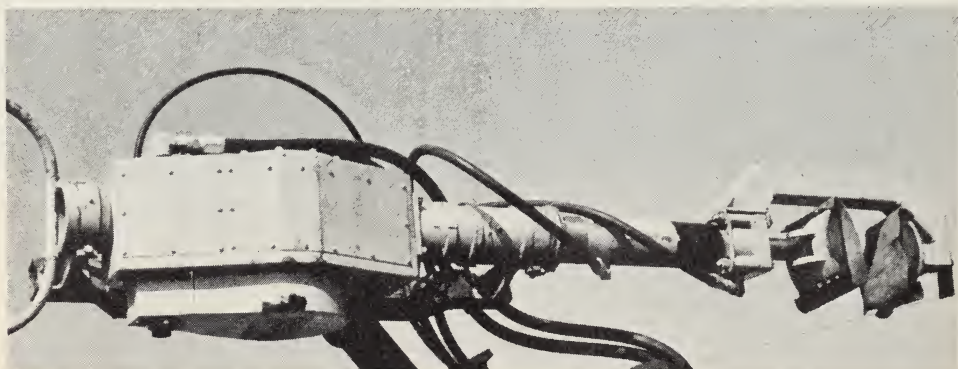


Fig. 11. Inertia shaker designed for use on olives.

ured to be in the range of 2 to 4 inches. The crank was approximately balanced to minimize the vibrations perpendicular to the desired direction of motion.

The clamp to attach to the tree was activated by a double-acting hydraulic cylinder with a relief valve in the line to limit clamping pressure. A check valve was used to maintain the grip under dynamic conditions. Each clamp pad was made of 30 durometer rubber, backed with a curved steel plate, and covered with leather approximately 6 inches square (fig. 12). This

type of pad was developed by Fridley and Adrian (1966) to minimize injury to the tree bark.

The inertia shaker was designed with a reciprocating weight of approximately 210 pounds and a total shaker weight of about 400 pounds, exclusive of mounting devices. The shaker was supported at its center of gravity to facilitate maneuverability and was designed so that when mounted on an appropriate support attachment could be perpendicular to limbs to minimize bark damage with the shaker directed

Fig. 12. Clamp developed to minimize injury to bark of trees.





Fig. 13. Catching frame developed for use on olives shown with canvas extended to position for collection of shaken fruit. Operator is preparing to maneuver shaker into position to shake.

toward the center of the tree to maximize fruit removal.

Catching-frame design

Field trials indicated the need to design a catching frame specifically for olives. The design objectives were: (1) to provide a frame which would support the inertia shaker previously described; (2) to permit the shaker to travel around each tree for the best attachment of the shaker on each limb; (3) to provide a large catching area while maintaining maneuverability of the shaker and the frame; (4) to provide a catching surface which would minimize fruit injury. Figure 13 shows the frame selected to accomplish these goals. The shaker and operator are supported on a linkage that in effect pivots about the tree trunk. Movement of the shaker required a low-profile catching frame; this was achieved by use of suspended canvas roll-out units which extend parallel to the tree row, to the front and rear of the main

frame. As the canvas is rolled in, fruit caught on the suspended canvas is delivered to a cross conveyor and then to an elevating conveyor. Fruit and debris are then separated at the end of the elevator by use of an air stream. Harvested fruits are handled in bins.

A complete harvester would have two catching units, one for each side of the tree rows. Length of the machine is 28 feet; however, by adding canvas, the unit extends to 34 feet. The roll-out units are extended hydraulically, using a pantograph linkage system which also maintains tension on the canvas as it is rolled in (fig. 14). Canvas tension in the extended position is controlled by the canvas roll drive motor. When the roll-out units are retracted, the pantograph linkage, collapses until it reaches a stop, then tilts up to allow fruit on the last portion of canvas to drain into the cross conveyor. Figure 15 shows the resulting compact machine ready to move to the next tree.

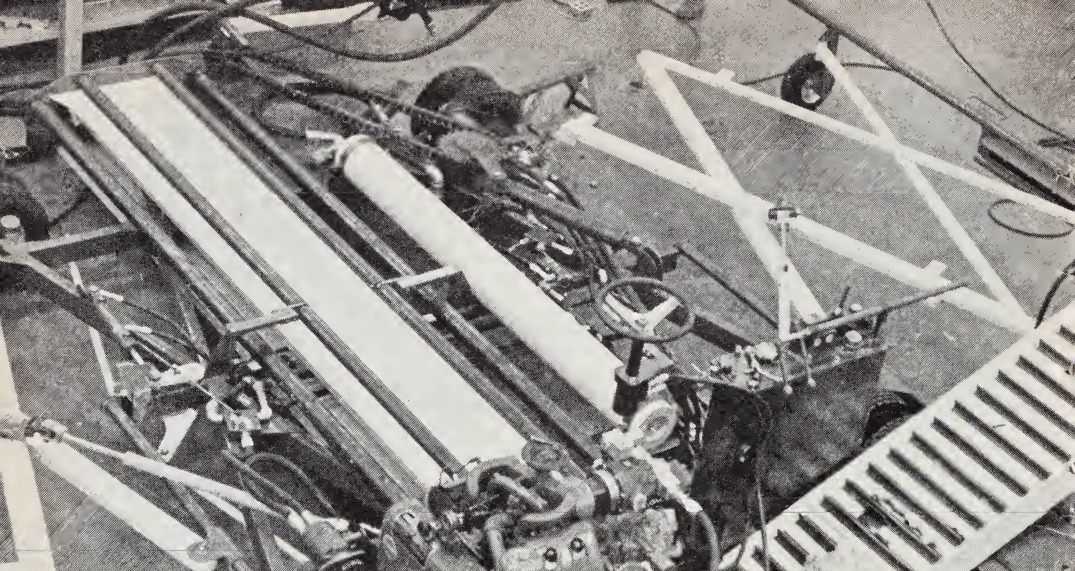


Fig. 14. Catching frame with collection canvas retracted to show pantograph linkage used to extend and support collection canvas.

Shaker support

The main shaker support linkage, which also carries the operator (fig. 16), allows the operator and shaker to swing around a point located at the center of the tree. The links in the arm pass one over the other in the center position and are chain driven to maintain alignment. The carriage and track assembly provides radial movement while a vertical hydraulic cylinder next to the shaker provides elevation changes. Controls for all the shaker positioning functions are in two, thumb-operated buttons located in the shaker

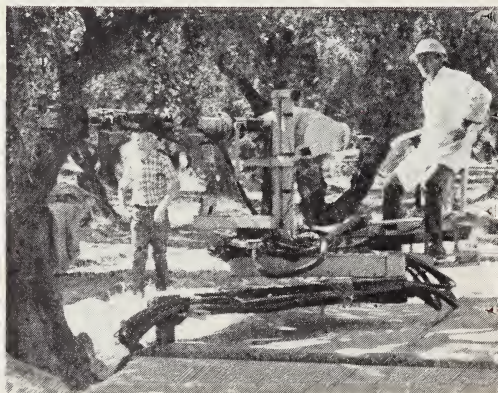
handle. These electrical switches are linked to solenoid valves located on the main frame.

An earlier design provided support for the shaker and operator on a single arm which was pivoted at a point on the edge of the frame about 3 feet from the tree trunk. This arrangement, although simple, was only satisfactory for movement through angles greater than 45 degrees to the tree row. When the operator attempted to shake a limb which was parallel to the edge of the frame he could not maneuver into a satisfactory position.

Fig. 15. Catching frame in position ready for moving to next tree.



Fig. 16. Shaker support linkage designed to permit movement of the shaker and operator around the tree in such a way that operator always faces toward center of the tree.



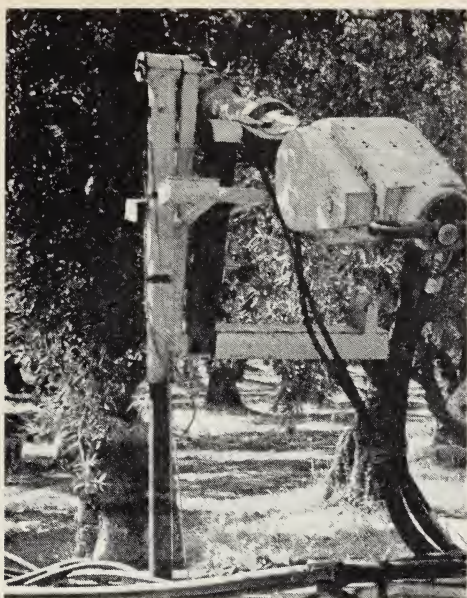


Fig. 17. Vibration isolation system showing torsion bar which isolates the vibration, hydraulic cylinder which elevates the shaker, and isolation support bracket which keeps the shaker in the correct position relative to the torsion bar.

Also, vertical movement of the early unit was accomplished by a four-bar linkage which elevated both the shaker and operator. This was abandoned, because low branches interfered with the operator.

Vibration isolation

The commonly used method of hanging a shaker on a short link to isolate the shaker vibration from the frame (Fridley

and Adrian, 1966) is not satisfactory when the shaker is operated at positions other than approximately horizontal. Therefore, a torsion-bar suspension was developed for vibration isolation of the olive shaker (Fridley, Shawver and Holekamp, 1970). The shaker is supported on a lever arm which is attached to one end of a torsion bar (fig. 17). The opposite end of this bar is attached to the isolation support bracket which is attached to the vertical hydraulic cylinder. By proper design of the lever arm and torsion bar, vibration isolation (transmissibility of $1/250$) was possible for a range of shaker positions from horizontal to a slope of 40 degrees.

Effective isolation requires that the lever arm and the shaker be approximately perpendicular. This in turn requires that the lever arm be displaced through the same angle as the shaker, when the shaker slope is changed during attachment to a limb. To accomplish this, the isolation support bracket was made to pivot at its attachment to the vertical hydraulic cylinder. A rubber bushing was used to restrict free movement of the pivot between the shaker and torsion bar lever arm. When shaker slope is changed, torque caused by the rubber bushing is applied to the isolation support pivot causing the support to correspond to shaker slope. Allowance was made for the static deflection of the torsion bar, resulting from the lever arm shifting from vertical, by positioning the isolation support pivot to keep the center of gravity of the shaker directly below the pivot at all times (fig. 17).

THE COMPLETE HARVESTER—FIELD TESTED

The complete harvester was tested for the number of trees harvested per hour, percentage of fruit removed, fruit and tree injury, and operating costs. Field tests were made on Manzanillo and Sevillano trees at several locations under various orchard conditions. Table 3 summarizes and compares some of these items with those of hand-harvested trees. Before these tests with the complete harvester, the shaker was tested without the catching

frame at two other locations on Mission, Manzanillo, and Sevillano trees.

Orchards used in these tests with the complete harvester were highly variable. Some had trees with dense, low-hanging foliage, long hangers, and many near-horizontal scaffold branches. One orchard had trees with a small amount of low-hanging foliage and three or four upright scaffold limbs per tree, but new shoot growth at the ends of old, heavy limbs had

TABLE 3
SUMMARY RESULTS OF MACHINE
HARVESTING OF OLIVE TREES
COMPARED TO THOSE OF
HAND-HARVESTING

Item	Result	
	Machine harvest	Hand harvest
Trees picked per hour.....	12-30	
Fruit removal (per cent).....	75-80	95-100
Fruit quality index:*		
Black-ripe process.....	3.70	3.80
Green-ripe process.....	2.50	3.56

* See page 9 for method of calculation.

resulted from topping two years earlier. Still, trees in another orchard were so weakened by olive knot that scaffold branches were extremely brittle. The plots harvested varied from only a few trees to 2½ acres per orchard.

In orchards with trees well adapted to machine harvest, up to 30 trees could be harvested per hour, but in orchards with poorly structured trees, as few as 12 per

hour could be harvested. Mobility of the machine with these latter trees was satisfactory; however, positioning the shaker was difficult, because a substantial number of the scaffolds had less than 40 degrees slope with the horizontal. In addition, operator visibility was impaired by low hanging foliage.

Fruit quality

Fruit samples collected for quality evaluation were handled before processing in one of three ways: salt solution (4 to 6 per cent brine), nonsalt solution (1.666 per cent lactic acid) or left dry in conventional lug boxes. The fruit was processed, graded, and evaluated on the basis of the quality index described on page 8. None of the field samples were sorted, but all samples chosen for comparison from the regular plant pack were, of course, graded. Field samples were processed either by commercial processors or the U.C. Department of Food Science and Technology, or both.

Fruit samples were taken from several places on the catching frame, as well as directly from the catching area and from the bins being filled. No significant differences

TABLE 4
QUALITY INDEX RATINGS OF SEVILLANO AND MANZANILLO OLIVES
THAT WERE MECHANICALLY HARVESTED COMPARED TO THOSE
THAT WERE HAND-PICKED

Olive variety, processor and harvest time:	Quality index rating* of olives collected by:						
	Experimental mechanical harvester with:					Hand-picking, and handled in:	
	Catching frame, and handled in:			Canvas roll-out and handled in:			
	Dry bins	Brine	1.66% lactic acid	Dry bins	Brine			Dry bins	1.66% lactic acid
Sevillano† processed by U.C. at:							
Early harvest (first pick)	3.53	3.15	3.39	3.17	.....	3.88	.....
Late harvest (second pick) . . . . .	.....	3.76	.....	.....	3.47	.....	.....
Late harvest (single pick) . . . . .	.....	3.79	3.83	.....	3.84	.....	.....
Commercial plant:.....	3.45	3.19	.....	3.20	.....	3.90	.....
Manzanillo‡ processed by U.C. at:							
Early harvest (single pick)	3.60	3.55	3.60	.....	.....	.....	3.77
Commercial plant:.....	3.63	3.64	3.78	.....	.....	3.70	3.77

† For Sevillanos, early harvest was October 7 to 10, 1969, and consisted of short-duration shaking on trees scheduled for two picks and normal shaking of single-pick trees. The later harvest was October 20 to 22, 1969, and consisted of a normal shaking, second pick on trees scheduled for two picks and normal shaking of single pick trees.

‡ For Manzanillos, the early (once-over) harvest was September 18, 1969.

* See page 9 for method of calculation.

were noted among the different locations, indicating that the fruit damage was not caused by elements of the catching frame.

Quality indexes for mechanically harvested fruit which had been black-ripe processed are given in table 4. The machine-harvested fruit had a lower index than hand-harvested fruit, primarily because of slight scars on the surface. However, it doesn't appear that with black-ripe processing, this difference will affect the commercial usefulness of mechanical harvesting.

The results with Sevillano olives indicate that better fruit quality is achieved by late harvest than by early harvest, probably because the fruit becomes less firm with advanced maturity, making it more capable of tolerating impacts without showing damage. Also, fruits harvested during the second mechanical shaking were better quality than those harvested the first shaking—indicating that fruits left on the tree are not seriously damaged during the first short-duration shaking period.

Fruit in salt solution showed indexes equivalent to fruit handled in conventional boxes, while fruit handled in the non-salt solution had indexes only about 2 per cent greater than did conventionally boxed fruit.

A comparison of quality between machine harvested olives and plant-pack of

hand harvested olives is given in table 5 for Manzanillo and Sevillano for both green-ripe and black-ripe processing. The plant pack was a control taken at random from processor's stock. Green-ripe Manzanillos, harvested by machine, had a quality index of 2.37 compared to an index of 3.59 for plant-pack green-ripe olives. Fruits processed black-ripe had an index of 3.82 for both machine harvest and plant-pack. Results with Sevillano olives were similar, with a green-ripe index of 2.57 compared to an index of 3.18 for black-ripe. The commercially processed black-ripe control sample had an index of 3.80.

Although fruit damage is much more apparent on green-ripe olives than on black-ripe olives, it may be possible to sort to attain satisfactory quality for green-ripe processing.

Fruit removal percentages

Complete data on the amount of fruit removal from the tree were obtained in some trials, but estimates were necessary during other tests, because workers could not be found to glean fruits that remained after shaking. Removal of Manzanillo olives ranged from about 50 to 90 per cent, and with Sevillano from 70 to 95 per cent. Mission olives left in the tree were mostly estimated by count, but they were comparable to Sevillano data. Poor

TABLE 5

QUALITY OF BLACK-RIPE AND GREEN-RIPE PROCESSED OLIVE FRUITS
AFTER MACHINE HARVESTING COMPARED TO THAT OF FRUITS
HAND PICKED AND HANDLED BY THE USUAL COMMERCIAL METHODS

Olive variety and source of sample	Processing method	Per cent of fruit with:				Quality index†
		No damage	No skin breaks; light visible scar	No skin breaks; heavily scarred and bruised	Skin breaks, cuts, and indentations	
Manzanillo:						
Machine-harvested	Black-ripe	82	18	0	0	3.82
Plant pack*	Black-ripe	83	17	0	0	3.82
Machine-harvested	Green-ripe	2	35	61	2	2.37
Plant pack*	Green-ripe	62	36	1	1	3.59
Sevillano:						
Machine-harvested	Black-ripe	43	39	12	6	3.18
Plant pack*	Black-ripe	86	10	2	2	3.80
Machine-harvested	Green-ripe	3	57	32	8	2.57

* A sample taken at random from warehouse of processor. These olives were sorted on the processing line; machine harvest samples were unsorted.
† See page 9 for method of calculation.

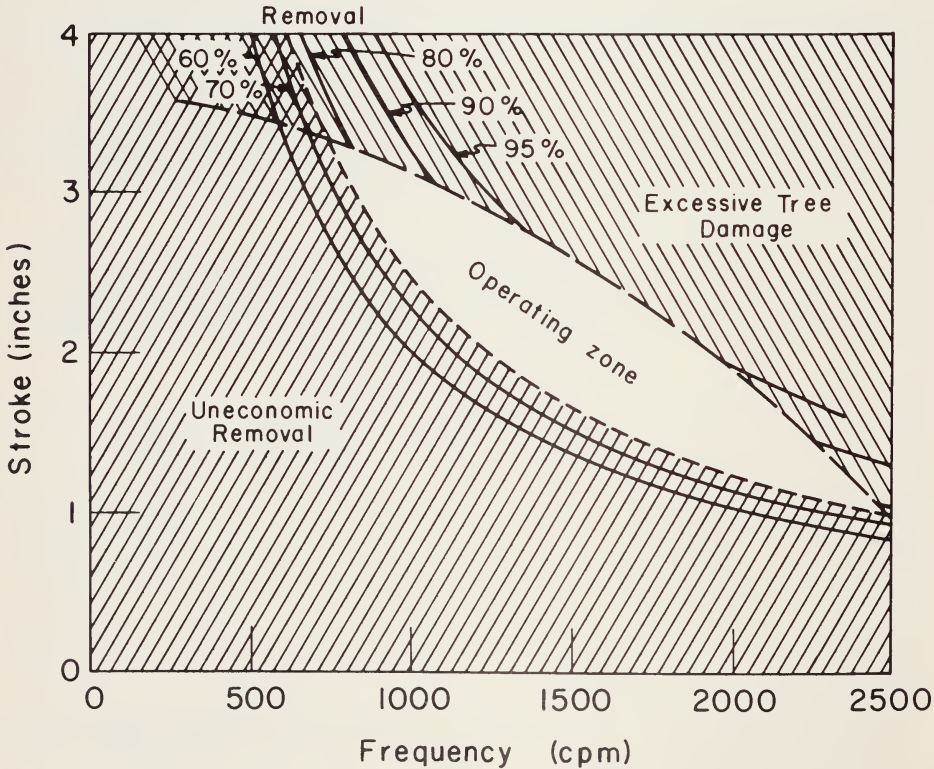
fruit removal was primarily due to long hanger growth, brittle tree structure, and, to a lesser extent, an inability to properly attach the shaker clamp to all scaffold limbs

A trial with Sevillano olives was planned to determine the effects of early, middle, and late season harvests, as well as "twice-over" harvesting. Removal results averaged about 76 per cent for both the early and late season harvest, with negligible difference between them. The "twice-over" harvest yielded a total removal of 86 per cent, with nearly 70 per cent of the fruit being removed by the first shaking. The increased fruit removal obtained with the "twice-over" harvest does not necessarily justify such a practice, unless the equipment operation is sufficiently

fast or other management factors warrant it.

The effect of frequency and stroke on fruit removal and tree injury is illustrated in figure 18. As mentioned earlier, per cent fruit removal changed from tree to tree and orchard to orchard depending upon tree structure and ease of detachment of the olives. As a result, the lines representing removal percentages on figure 18 shifted to the left under good conditions and to the right with poor conditions. The line representing the minimum per cent removal for economic harvest, while influenced by several factors, was usually near the 75 or 80 per cent line. However, it approached 90 per cent with low harvest rates, high machine costs, poor yields, high fruit price, or low hand-harvest

Fig. 18. Effect of frequency and stroke on removal of fruit without excessive tree damage or economic loss. The unshaded area gives the zone of recommended operation. The boundaries of this zone vary depending on orchard conditions, including tree pruning, ease of fruit detachment, tree vigor, market value of the fruit, and the like.



cost. The tree damage line shifted to the left with brittle trees that could not tolerate shaking and to the right for strong, healthy trees. Figure 18, therefore, demonstrates a satisfactory operating zone which changed among orchards and even among trees. Such a zone can be very small (or possibly nonexistent) for trees which are particularly brittle, have long hangers, and fruit which is tightly attached. In contrast, the zone can be large for trees which are properly pruned, not brittle, with fruit that detaches with average ease. In general, the desirable operating zone was 1½ to 3 inch strokes with frequencies of 2,000 to 1,000 cycles per minute. These values are approximately 50 to 100 per cent higher than those used for most deciduous fruits and necessitate an approximate five-fold increase in power.

Economic aspects

Based upon the results given in table 3, and the assumptions of five years' machine life, 12 per cent taxes and interest, 70 trees per acre, and no reduction in fruit quality, harvest costs for a variety of conditions were calculated and compared to those of hand harvest. To account for fruit loss resulting from mechanical harvest, re-

sults were compared on the basis of net returns (considering harvest only) as follows:

$$\frac{\text{Net return by machine harvest}}{\text{Net return by hand harvest}} = \frac{(\text{Yield}) (\% \text{ removal}) (\text{price}) - (\text{harvest cost})}{(\text{Yield}) (\text{price}) - (\text{yield}) (\text{harvest cost})}$$

The calculated ratio equals 1.0 for a break-even operation, is greater than 1.0 when machine harvest provides the greatest return, and is less than 1.0 when hand harvest gives the best returns. Table 6 gives the net return for a variety of typical operations. The machine costs are estimated, based upon experience with similar tree-fruit harvest equipment. Machine use of 300 hours represents an eight-hour working day for 37.5 days during the season. Two shifts, with some night operations, are possible, which gives a 600-hour season (16 hours per day for 37.5 days). Careful study of table 6 shows that machine performance, yield, fruit value, and hand-harvest costs are more important than machine cost. For example, note the substantial advantage to machine harvesting fruit with low dollar value by comparing lines 1 and 7 in the table. On the

TABLE 6
COMPARISON OF CALCULATED NET RETURNS FOR VARIOUS
HYPOTHETICAL MECHANICAL OLIVE-HARVESTING
OPERATIONS WITH MANIPULATED VARIABLES*

Harvest machine cost	Duration of machine use	Harvest rate	Fruit yield	Fruit removal	Fruit value	Hand-harvest cost	Net return†
<i>dollars</i>	<i>hours/season</i>	<i>trees/hour</i>	<i>tons/acre</i>	<i>per cent</i>	<i>dollars/ton</i>	<i>dollars/ton</i>	<i>ratio</i>
30,000	300	15	3	75	325	125	0.96
25,000	300	15	3	75	325	125	0.99
30,000	600	15	3	75	325	125	1.06
30,000	300	20	3	75	325	125	1.02
30,000	300	15	4	75	325	125	1.02
30,000	300	15	3	85	325	125	1.12
30,000	300	15	3	75	250	125	1.08
30,000	300	15	3	75	325	150	1.01
25,000	300	20	4	80	325	125	1.17
25,000	300	15	2	75	325	125	0.82
35,000	300	20	4	80	325	125	1.13
35,000	300	15	2	75	325	125	0.77

* The indicated variables are the only factors changed relative to the first value given in each vertical column.
† Ratio of net return associated with machine harvest to net returns associated with hand harvest.
Example: Row 2, reading horizontally, gives the net return associated with a \$25,000 machine compared to that with a \$30,000 machine given in row 1; row 3 compares net return for 600 hours of machine use to net return given in row 1 for 300 hours; etc. By comparing the first eight rows, it can be noted that increasing fruit removal from 75 to 85 per cent gives the best net return.

other hand, if a grower could use a \$35,000 machine and had two orchards which could be represented by the last two lines of table 6, best management practice would be to use machine harvest for the conditions illustrated in the next to last line and use hand harvest for those conditions represented in the last line.

Good management, therefore, is essen-

tial for the best possible returns. In addition to such obvious management practices as keeping equipment maintained, having a healthy well-cared-for orchard, and employing responsible operators, good management must include consideration of how yield, fruit value, labor cost, fruit removal, and average harvest rate affect the economics of harvest.

CONCLUSIONS AND RECOMMENDATIONS

The practicability of mechanically harvesting olives in California was demonstrated. For highly successful mechanization of olive harvesting, all four of the following are required: (1) a properly designed machine, (2) healthy trees pruned for machine harvesting, (3) proper management, and (4) an effective abscission inducing chemical. Pruning trees for machine harvest and the use of effective abscission chemicals are considered to be of equal importance. A good machine used on well-trained trees, but without the abscission chemical, can leave 20 per cent of the fruit on the trees. While use of an abscission chemical will undoubtedly improve removal of fruits, good pruning practice and a shaker designed for olives still will be essential. Failure to use a properly designed machine or failure to prune trees for mechanical shaking will result in unacceptable fruit removal, even if an effective abscission chemical was available.

Fruit removal, as well as fruit quality, are poorest at the beginning of the harvest season. With a few exceptions, good removal requires shaking of the primary scaffold branches of the tree with a stroke in the range of $1\frac{1}{2}$ to 3 inches at a frequency of 2,000 to 1,000 cycles per minute, respectively. Too long a stroke and/or too high a frequency leads to excessive limb breakage. Low frequencies, used in combination with a long stroke, cause fruit scattering, while high frequencies cause considerable leaf removal. Short-duration shake (usually about two bursts of less than one second duration), as well as proper catching equipment and careful handling of the fruit, are necessary to

minimize fruit injury and tree damage. Shaker stroke and frequency should be adjusted to suit each limb; such adjustments could easily result in fruit removal percentages equal to or better than the "twice-over" harvest. During the trials the shaker stroke and frequency were varied frequently, with the final adjustments a compromise between too violent a shake on small or brittle limbs and too mild a shake on very large limbs.

The catching area should extend at least 5 feet beyond the tree on all sides. While elaborate decelerator strips and padding are not essential, hard surfaces and sharp edges against which olives might impact should be avoided. Canvas on the ground can be satisfactory if the soil surface is cleared of rocks or sharp clods, is padded by grass, or if a padding material is used with the canvas.

How to prevent root and soil damage by heavy equipment

Use the minimum weight equipment. Keep equipment out of the orchard as much as possible when the soil is wet. Use a heavy sod cover culture in the orchard (to sustain and distribute the weight of the harvesting equipment).

How to prune for machine harvesting

Pruning must not (1) result in a permanent reduction in total fruit-bearing surface; (2) be a complicated system requiring high labor costs; (3) involve annual heavy pruning which reduces yields by stimulat-

ing production of vegetative, nonfruitful shoots.

Aim for an open and vase-shaped configuration with four to six scaffold branches and no low, hanging branches below a height of 6 feet. The trunk should be about 2 feet high to permit good closure of the catch frame. Low, limber fruiting wood should be shortened or removed, not only because fruit growing on these branches is almost impossible to remove by shaking, but because they block the operator's view of the scaffold branches to which he must attach the shaker clamps. Loss of fruiting wood by removal of low-growing branches can be offset by allowing the tree to grow taller. Fruits on upright,

growing branches are readily removed by shaking, regardless of height.

Secondary branches that are also curved do not readily give up their fruit when shaken. For this reason, the tree should be analyzed carefully after shaking, and branches with a substantial amount of fruit still remaining should be pruned out. Redirect tree growth into sections where shaker energy is high.

Previously pruned trees (for hand-picking) require fairly severe pruning for machine harvesting. Again, the goal should be the open, vase shape described above. Cutting should be gradual, over a period of several years (Opitz and Rizzi, 1969).

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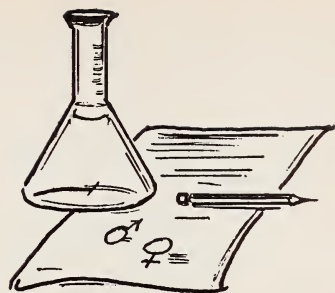
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